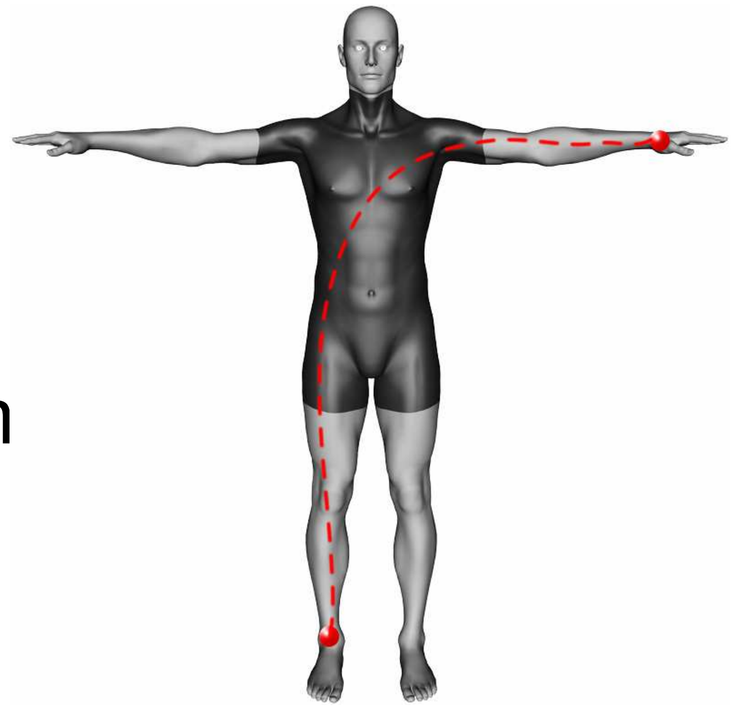
Body Coupled Communication

Presentation By:

Adam Barth…Again

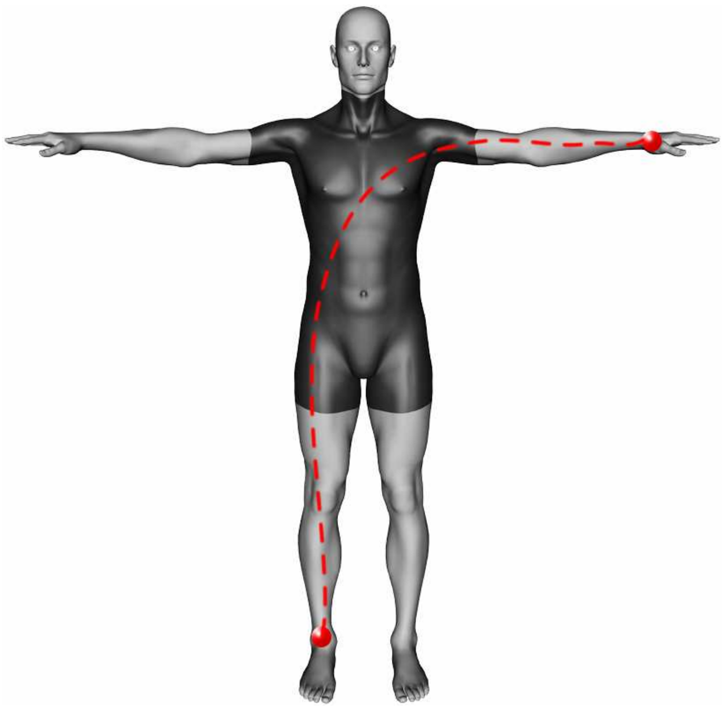


Types of Communication

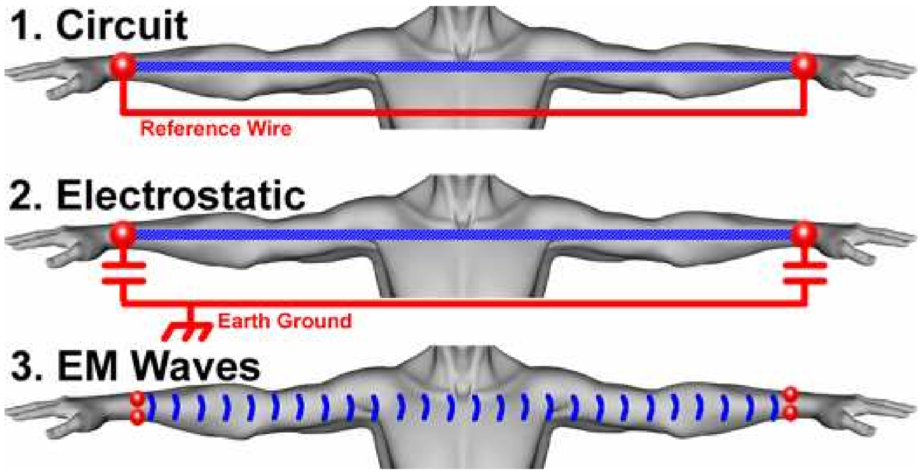
- Optical/Infrared
  - Requires line of sight
  - Omni-directional devices can consume a lot of power
- Far-field (RF)
  - Omni-directional (good/bad?)
  - Received power reduces by $1/r^2$
    - Eavesdropping?
    - Off-body communication?
- Near-field (magnetic/electrostatic)
  - Normally not omni-directional
  - Received power reduces by $1/r^3$
    - Privacy?
    - Distance limitations?

What is BodyComm

- Can be considered near-field or somewhere in between
- Uses the human body as a transmission medium
  - Health concerns?
- Generally limits communication to items in contact to the body
- Normally operates at low frequencies
  - Body absorption



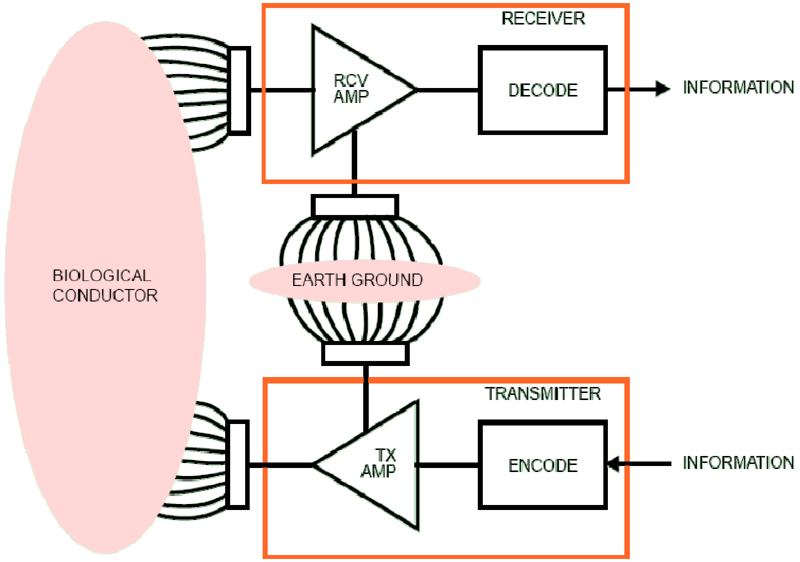
Types of BodyComm



- Which is best for BANs?
  - External dependence
  - System complexity
  - Wearability
- How do they compare to RF communication?

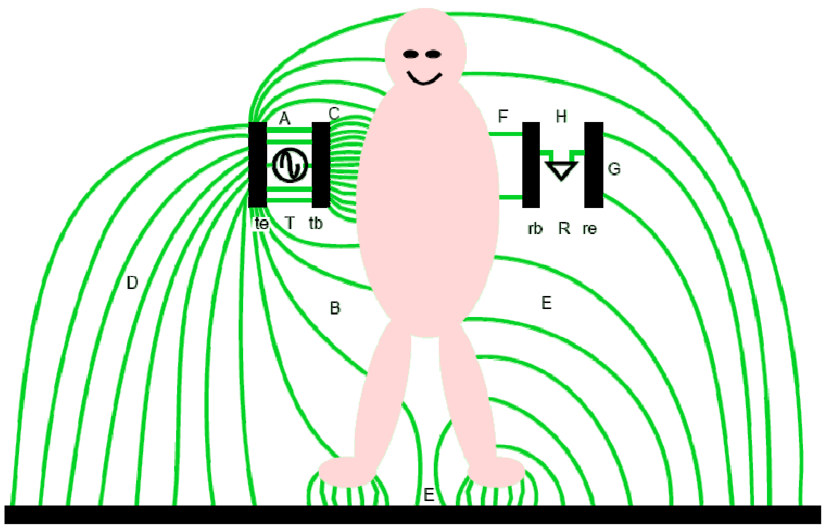
Electrostatic BodyComm

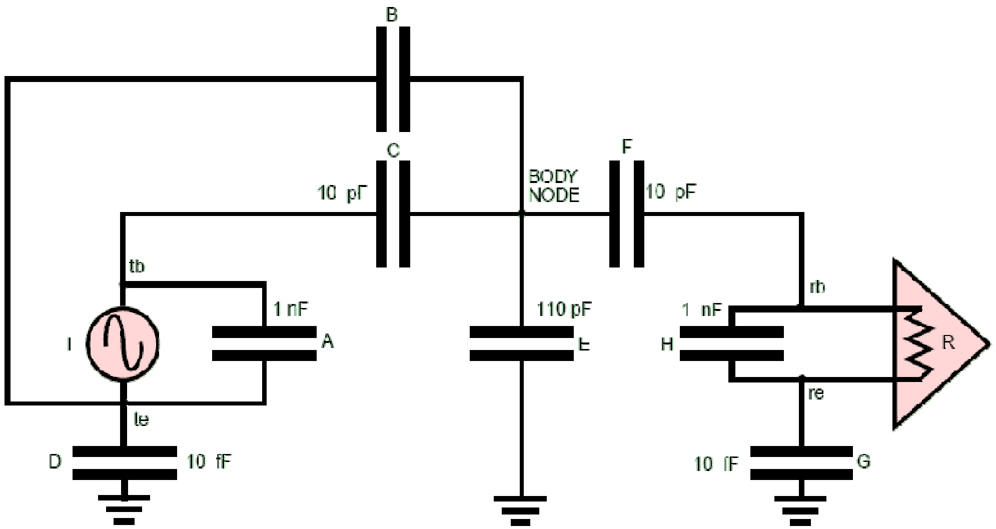
- Zimmerman (1996) MIT and IBM
- Electrostatic coupling
- Relies on small capacitive coupling to common “earth” ground



Electrostatic Models

- Electrostatic circuit with external ground reference
  - What capacitances are assumed?
  - How can they vary?



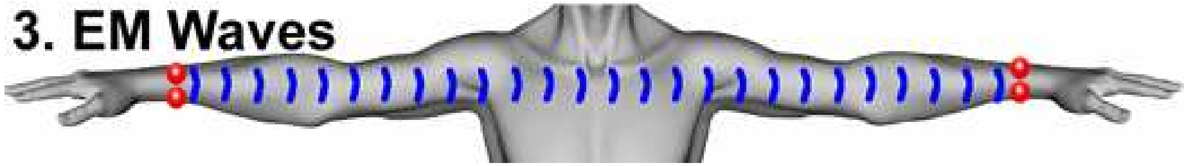


Electrostatic BodyComm

- Practicality:
  - Somewhere with strong “ground” capacitance is recommended
    - Shoe computer?
  - Commercial systems are available
    - RedTacton

- Would this work for BAN application?
  - Entertainment/Gaming
  - Medical

Waveguide BodyComm



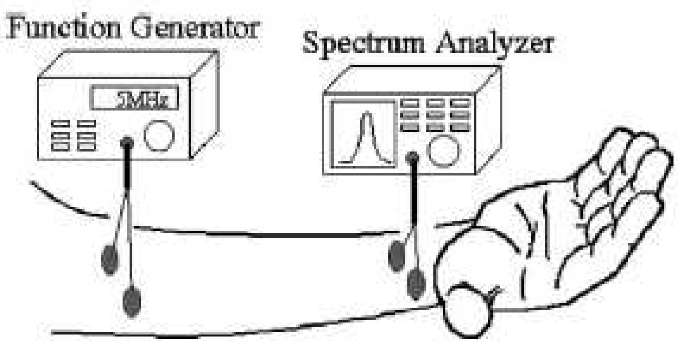
- Uses the body as a waveguide for EM waves
- Little to no dependence on external environment
- Uses two transducers at each site

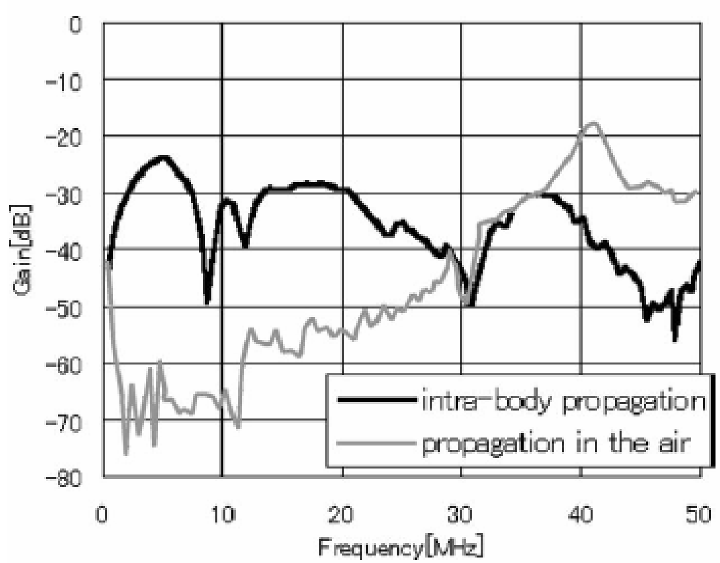
Waveguide BodyComm Research

- Keisuke Hachisuka (University of Tokyo)
- Experiments using Ag-Cl electrodes
  - Frequency characteristics
  - Electrode pair patterns
  - Electrode compositions
  - Electrode placement on body

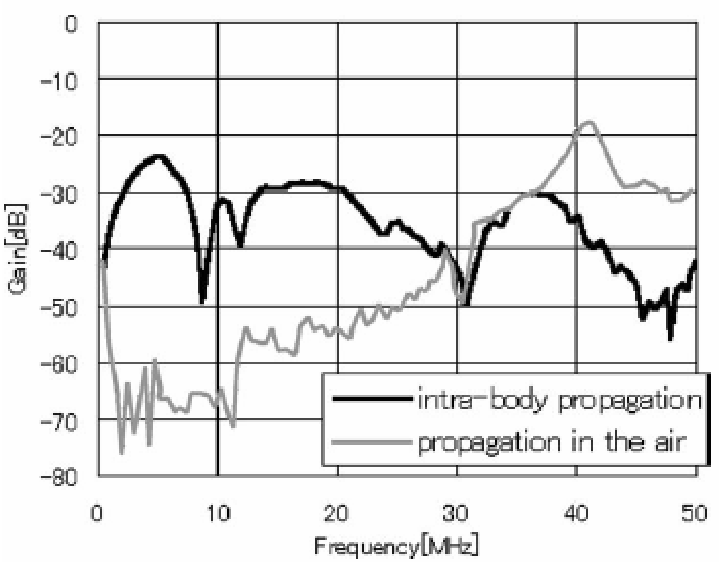
Frequency Experiments

- Electrodes on a forearm
- Frequency sweep from 1-50 MHz
- Shown to be better than airborne propagation
  - Problems?
  - Ambiguities?

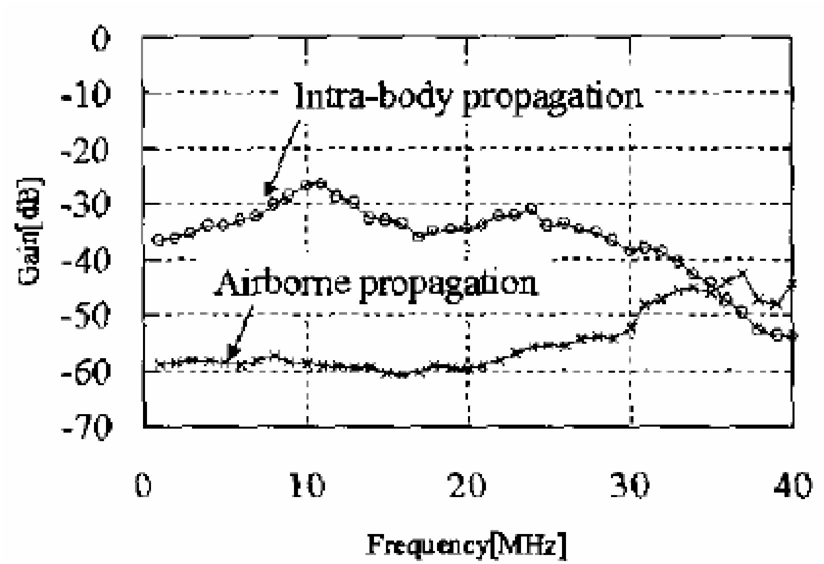




Frequency Results



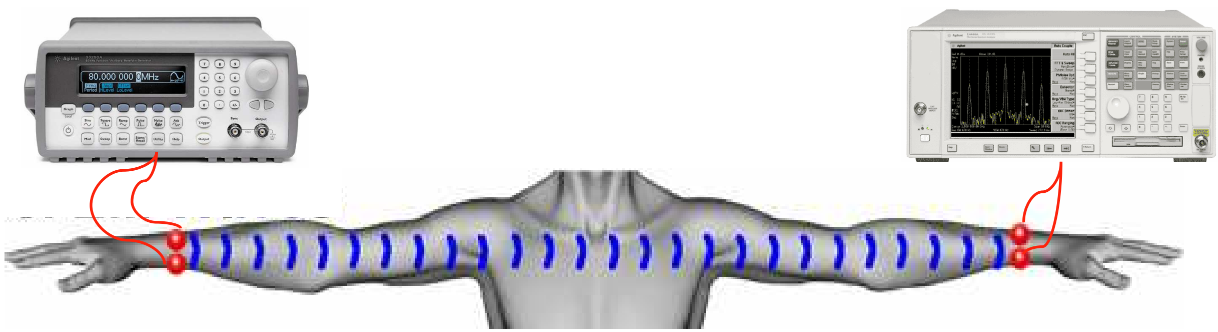
Hachisuka (Sensors and Actuators, February 2003)



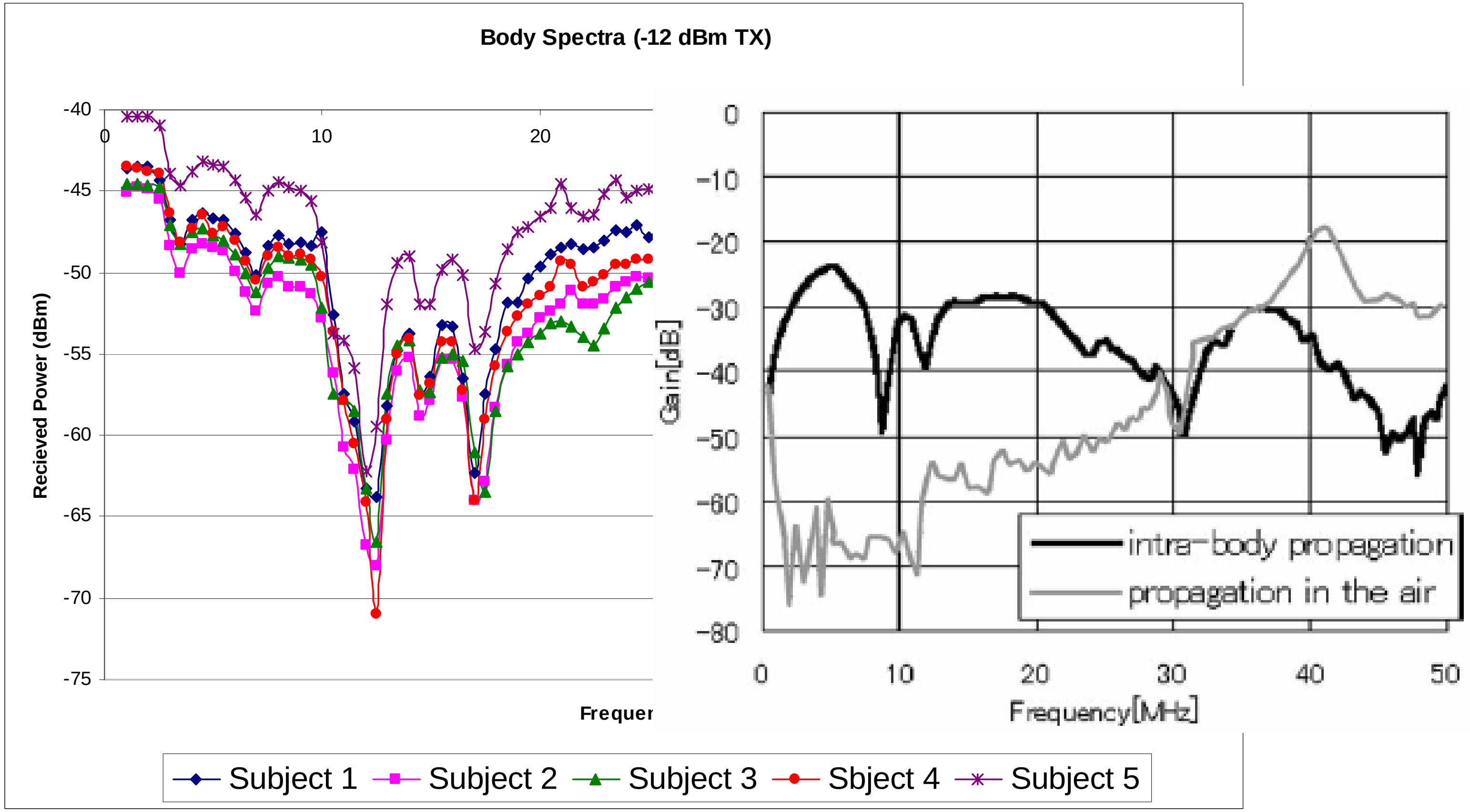
Hachisuka (the 12th International Conference on Solid State Sensors, Actuators and Microsystems, June 2003)

Our Frequency Tests

- 5 test subjects (Harry, Dincer, Mark, Me, and two females 20-23 years of age)
- Two carbon conductor electrodes on each wrist
  - One set connected to RF function generator (-12dBm TX power)
  - One set connected to spectrum analyzer
- Frequencies swept from 1-50 MHz



Our Frequency Results



Our Frequency Results

- What do these results show?
  - Relative consistency across subjects
  - Common resonant frequencies
  - Excellent receive strengths!!
    - Even without matching impedance to body

Waveguide Frequency Tests

- Problems with tests?
  - Common ground plane
  - Electrodes
    - Feasibility
    - Unknown frequency characteristics
  - Availability of small, low-power transceivers at the frequencies tested

  - Other tests are needed
    - Some have already been done

Electrode Pair Pattern Tests

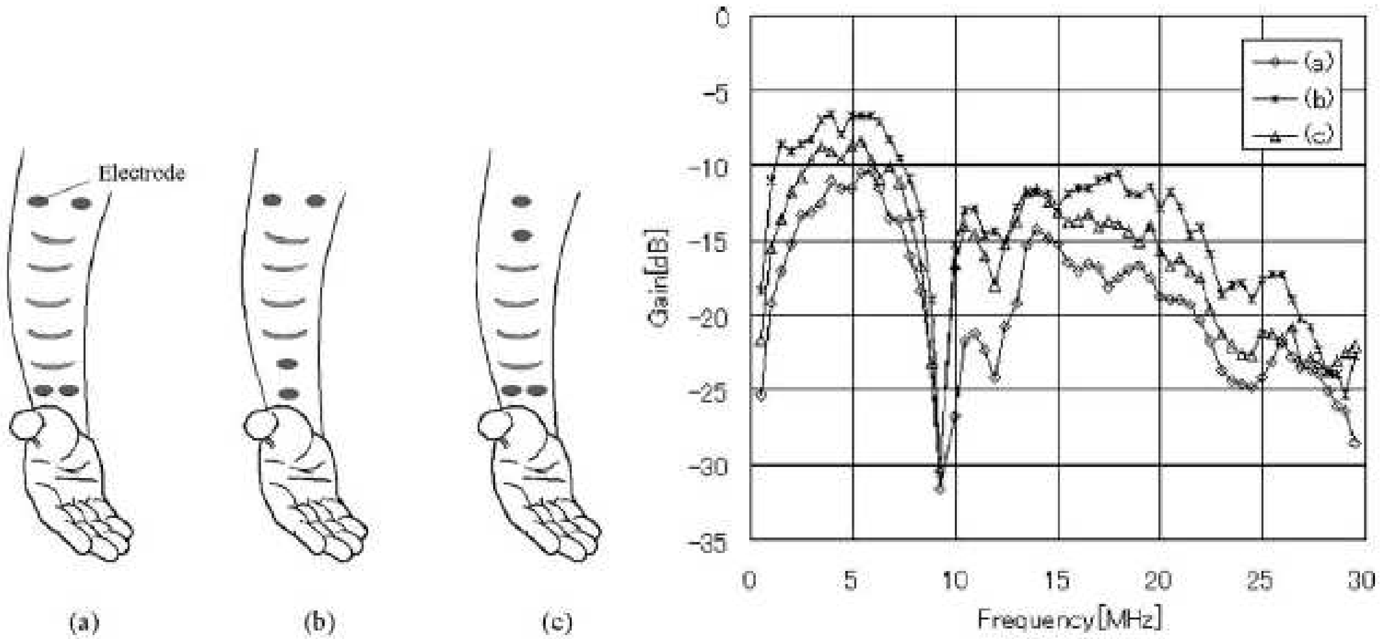
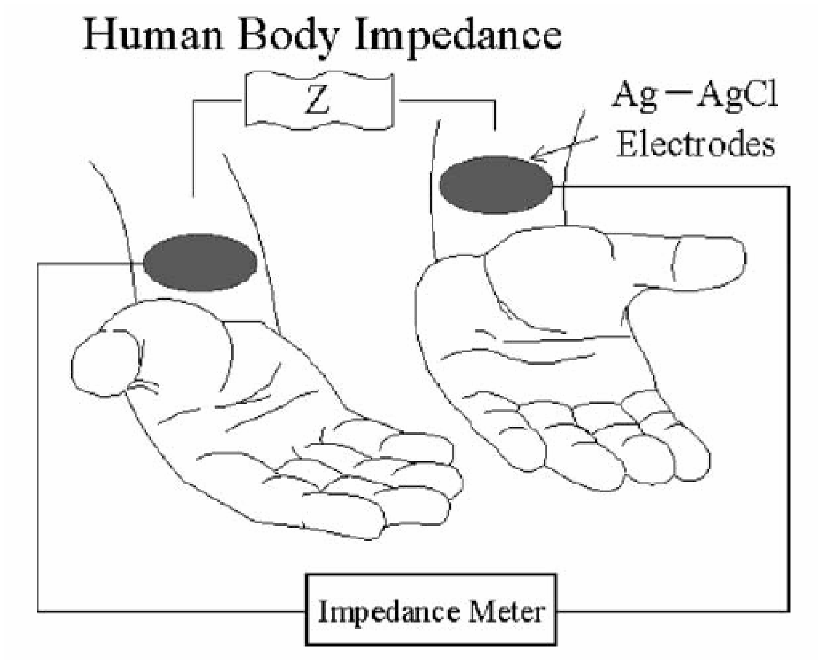
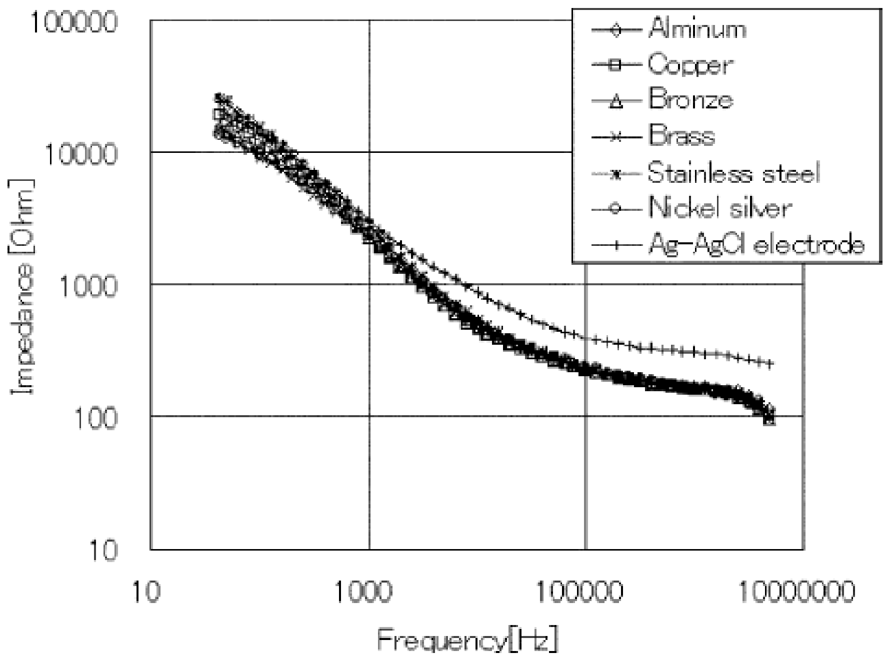


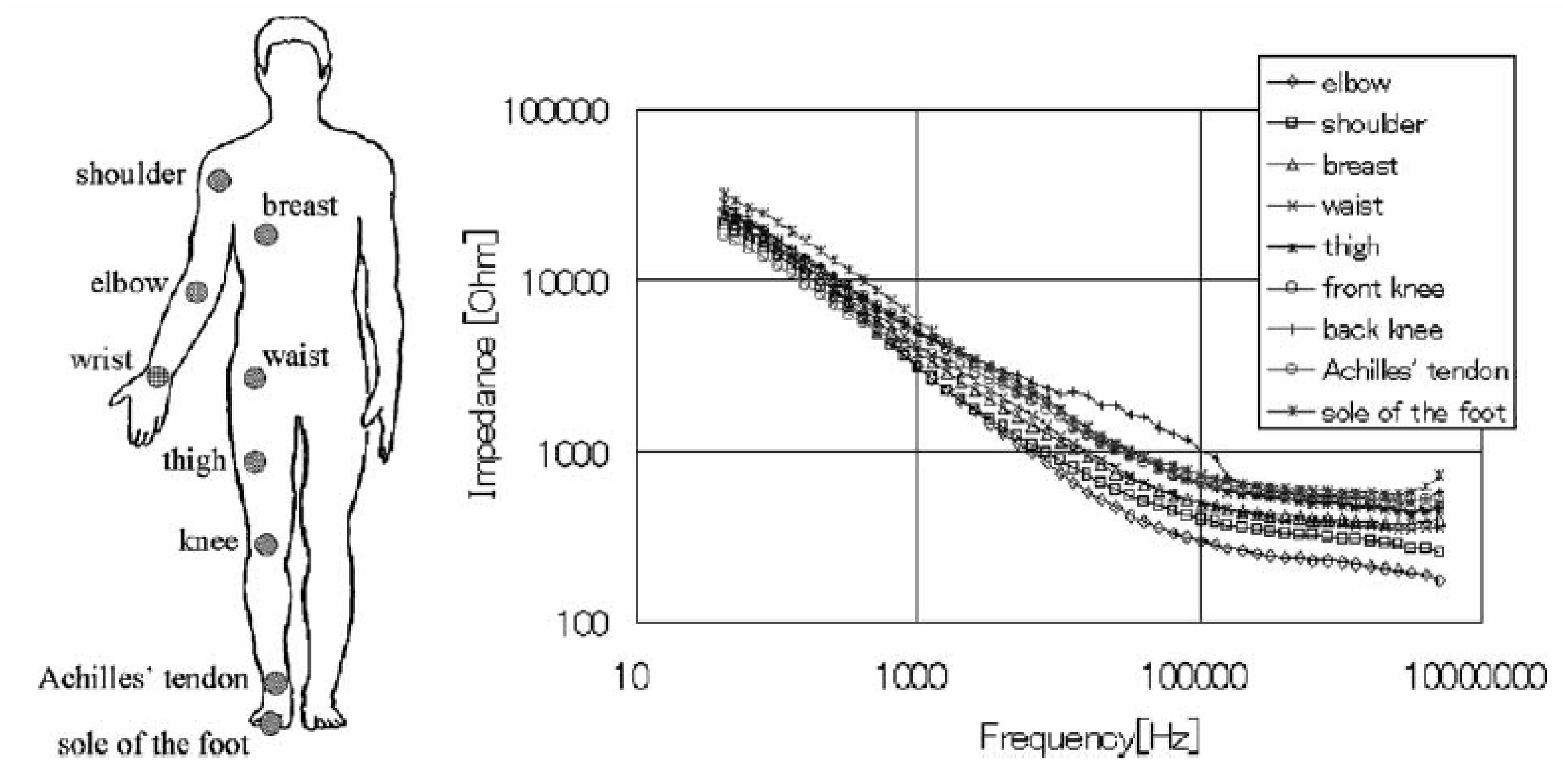
Fig. 6. Differences in propagation gain for three patterns of electrodes.

Electrode Impedance Tests



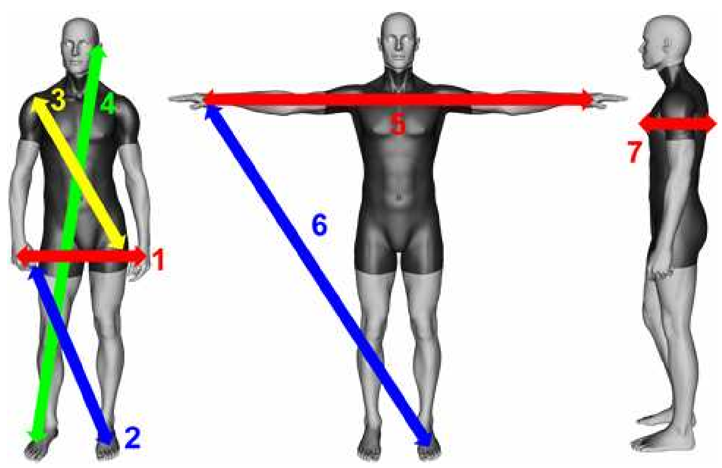


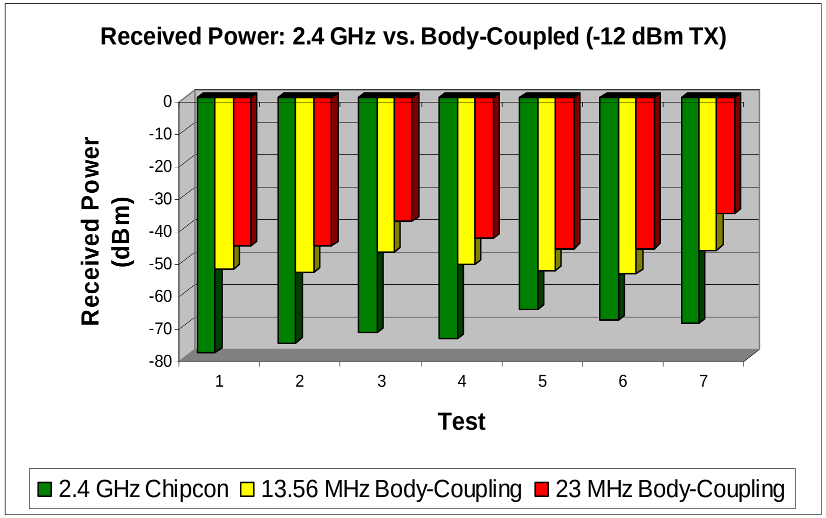
Electrode placement Tests



Comparison to 2.4 GHz

- 13.56 and 23 MHz carriers were selected for comparison
- Conducted tests with various positions on the body of subject 1





13 to 34 dB improvement over 2.4 GHz (between 20X and 2500X better)

Comparison to 2.4 GHz

- What do we gain with BodyComm?
- FSK Equations:

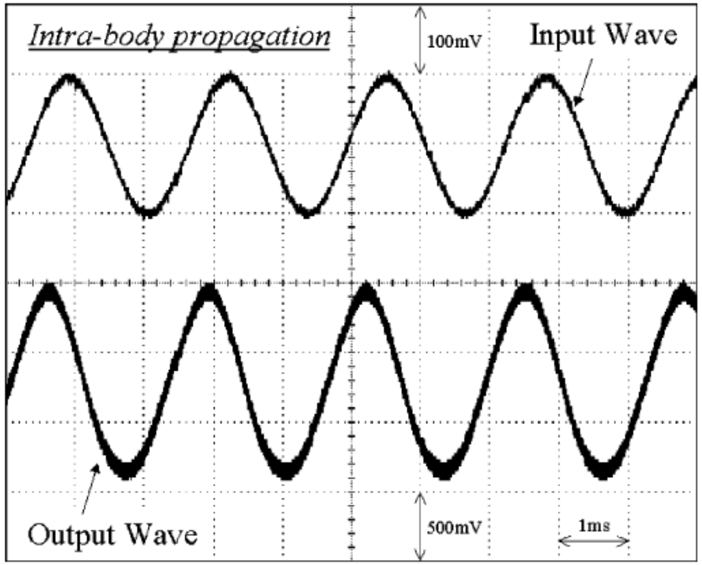
$$P_p = 1 - \left(1 - P_e\right)^N \qquad (1)$$

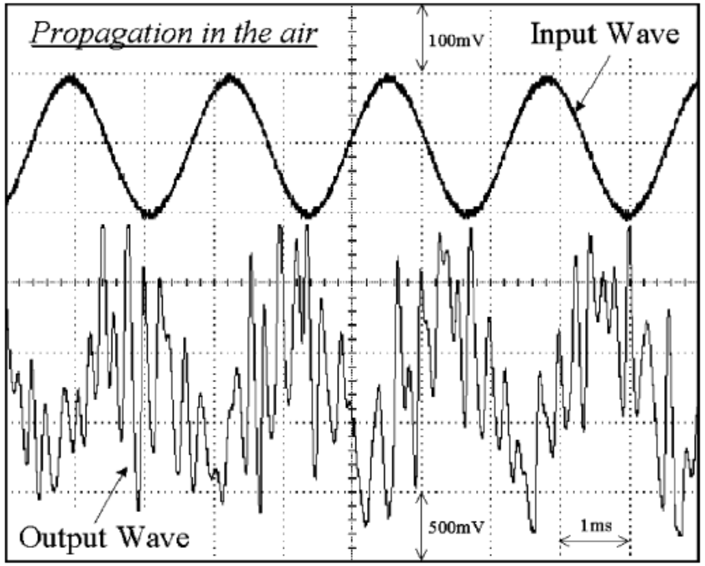
$$Pe = \frac{1}{2} e^{-\frac{E_b}{2 \cdot N0}} = \frac{1}{2} e^{-\frac{P_r}{2 \cdot N0 \cdot Rb}} \qquad (2)$$

- ZigBee boasts 1% PER, 1000bits/packet, and 250kbps throughput at -92 dBm RX power
- With reasonable assumptions for N_0 and T_{sys}, we could transmit at around -52 dBm and see the same results

BodyComm Prototype

- Analog FM transmission at 10.7 MHz
- Assembled from all COTS components at low cost





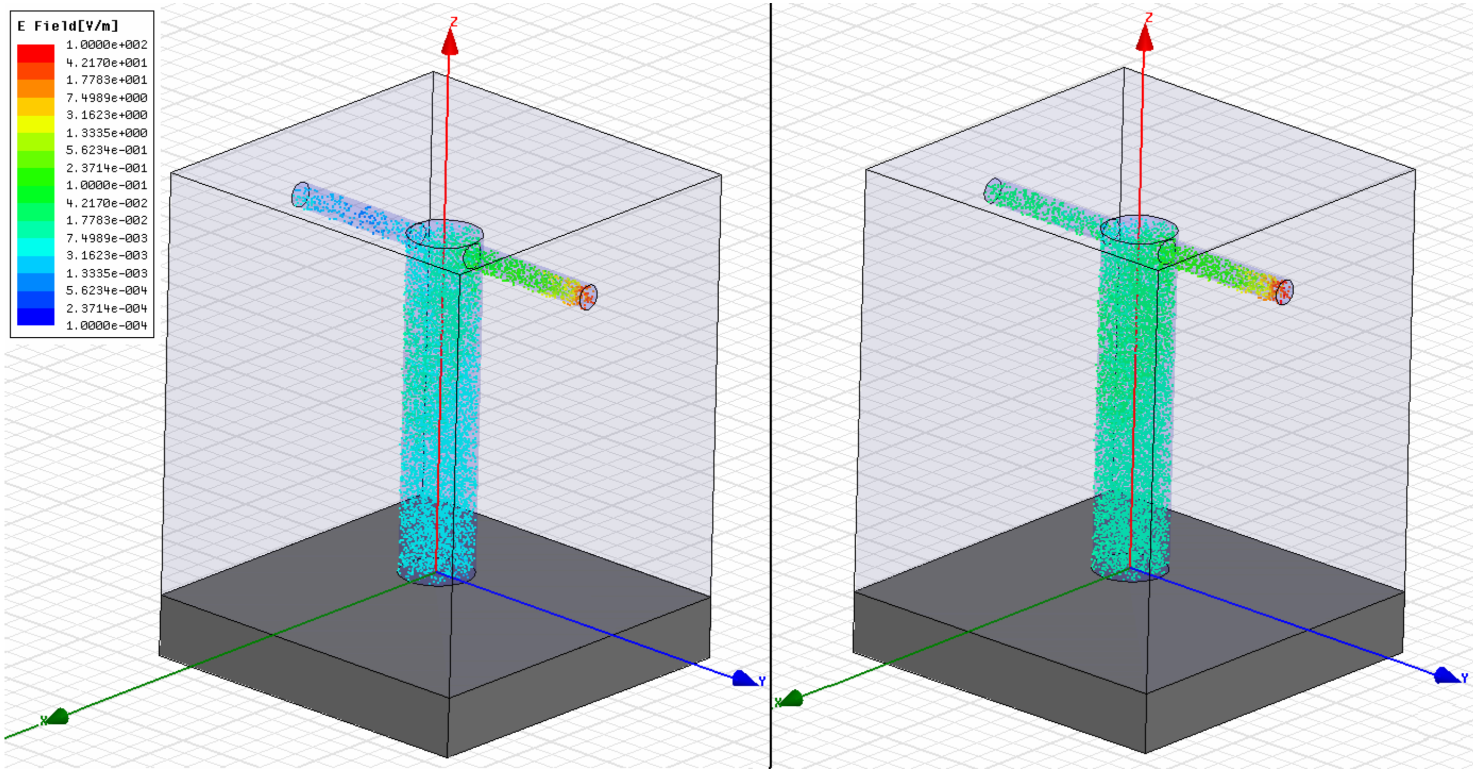
BodyComm Theory

- What is actually going on with waveguide BodyComm?
  - ¼ wave length at 10.7 MHz is 28 meters
- How much radiation is there away from the body?
- What accounts for small variations among test subjects?
- What can we gain from knowing all of this?

BodyComm Theory

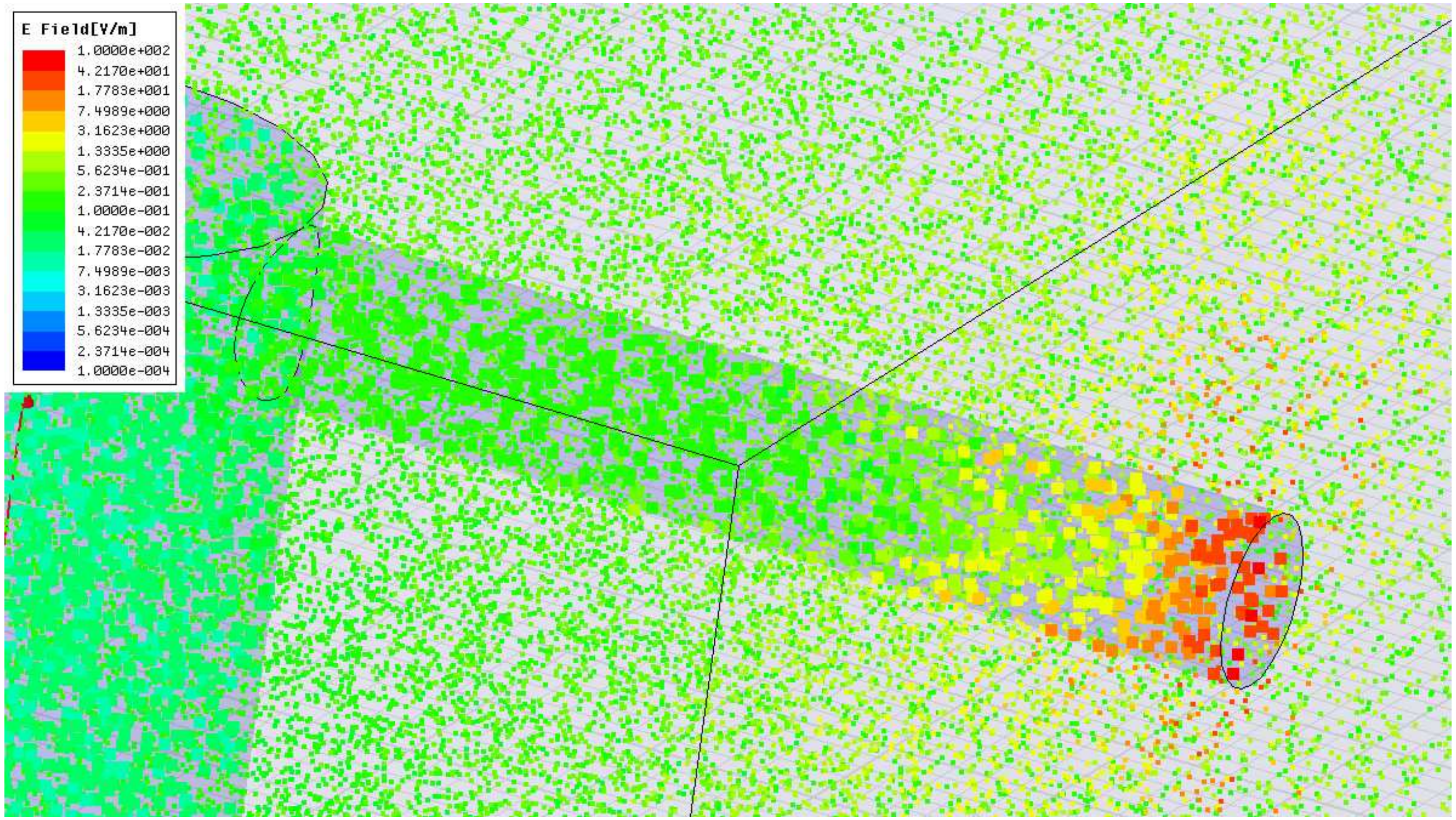
- One way to answer some the aforementioned questions is by constructing a model of the human body’s impedance (bio-impedance analysis)
- Most research in this area is somewhat proprietary
  - Consumer scales that give body fat, etc.
- A simple model can be constructed using HFSS
  - 3 cylinders (two arms and one body), with input and output ports on the right and left arms
  - 0.2 Siemens/m was used for the conductivity
  - 70 was used for the relative permittivity constant

HFSS simulation



The magnitudes of the E-field inside the body

HFSS Simulation



The magnitudes of the E-field inside the body and the air around the input arm

HFSS Simulation

Frequency	Impedance Real and Imaginary			
	13.56 MHz		***23 MHz***	
	Left Wrist	*Right Wrist*	*Left Wrist*	*Right Wrist*
Left Wrist	0.982 + j162	1.797E-5 – j463	0.948 + j149	4.934E-5 + j96.2
Right Wrist	*1.799E-5 – j463*	*0.983 + j163*	*4.934E-5 + j96.2*	*0.951 + j151*

Table 1. HFSS Impedance results.

Frequency	E-Field Magnitude			
	13.56 MHz		***23 MHz***	
	Left Wrist	*Right Wrist*	*Left Wrist*	*Right Wrist*
Left Wrist	0.98139	1.80E-05	0.94796	4.93E-05
Right Wrist	1.80E-05	0.98256	4.93E-05	0.95124

Table 2. HFSS E-Field Magnitude simulation results.

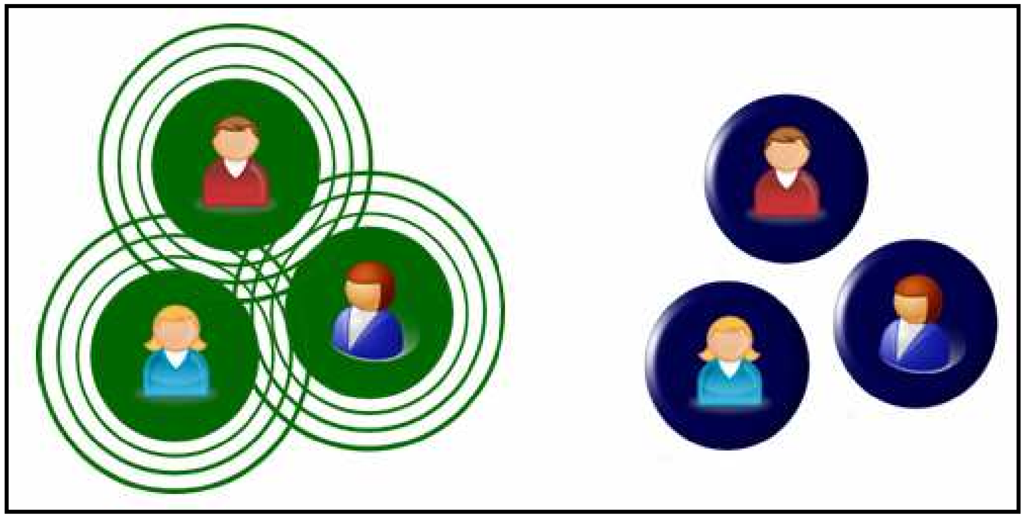
Ideas for More Experiments

- HFSS has a human model built for use in MRIs
  - Using this could get much more accurate simulation results
- Decouple from common ground plane and repeat receive strength measurements
- Use an anechoic chamber to measure radiated energy
- See if it can be capacitively coupled to the skin

BodyComm Privacy

- What are the implication of a “body-contained” network
  - Malicious attacks are limited to very close proximity
  - Facilitates spatial reuse
  - Reduces interference in dense environments

RF Radiation



BodyComm “bubbles”

BodyComm Applications

- What applications could benefit from BodyComm?
- What applications should remain RF?
- Is there enough demand for a BodyComm bote?

BodyComm Implications

- Should this still be considered a BAN?
  - What is the difference between BSNs, BANs, and PANs
- What will BodyComm do to processor power requirements?

Questions?